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# Wideband, Bidirectional Lightguide Communication With an Optically Powered Audio Channel

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*The feasibility of bidirectional speech-television communication over a single-strand lightguide, with emergency optical powering of the remote station telephone, has been demonstrated. The remote circuits drew ~250 μA at 0.9 volt from a double-heterostructure photovoltaic detector at 0.65 mW of received optical power; the detector low-pass response into 50 ohms was down 6 dB at 60 MHz. The optical packages featured GRIN-lens bidirectional couplers and, at the remote station, a low-threshold-current, buried-heterostructure laser.*

## I. INTRODUCTION

Lightguides connecting remote customer stations to a central switching office would make wideband telecommunications available to large markets. A two-wavelength, bidirectional link utilizing single-strand optical fiber might be economical compared to rechargeable batteries or auxiliary metallic conductors, particularly if used with an optical detector capable of powering the telephone channel during electric utility outage at a remote station. The feasibility of incorporating emergency optical powering into a wideband, two-way optical link is described below.

Both wideband and optically powered services can be realized with the GaAlAs photovoltaic diode used in previous demonstrations of

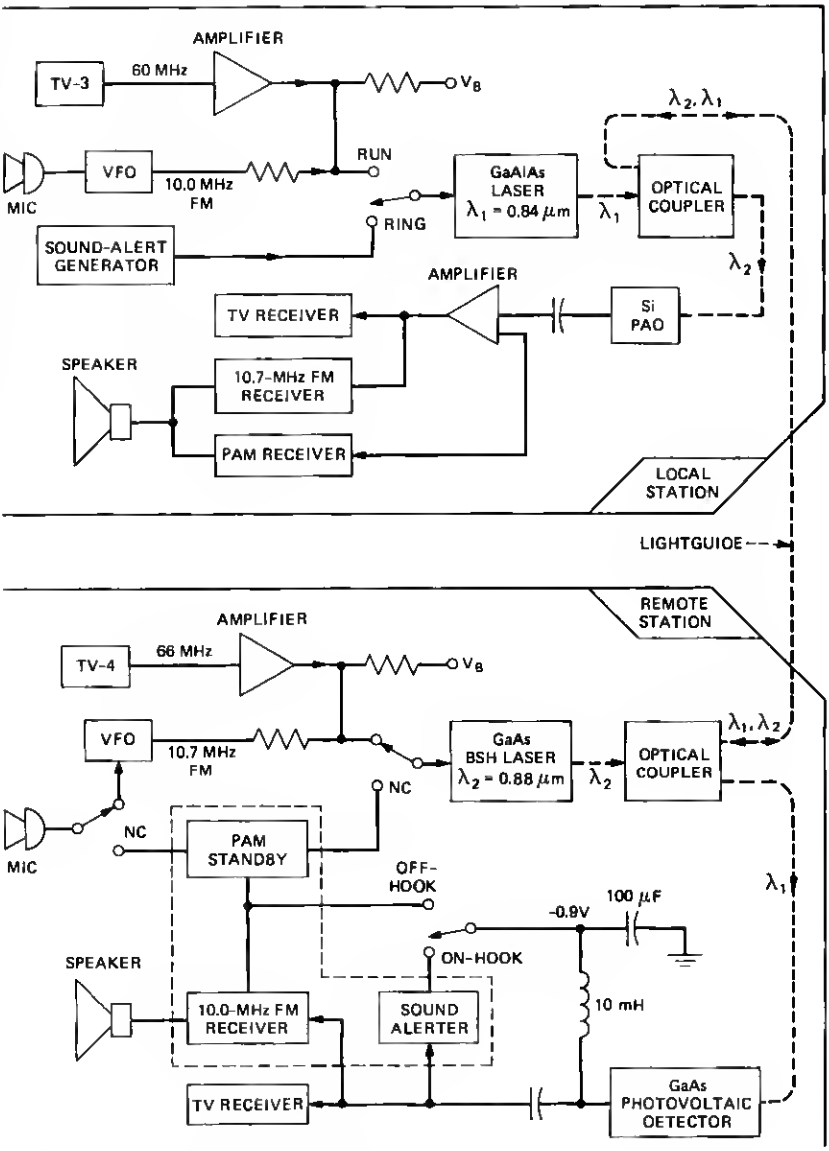
optically powered speech signalling[1] and sound alerting[2] at a remote station. This detector provides efficient photovoltaic conversion[3] along a high-resistance (3-kilohm) load line and short-circuit frequency response extending into the television carrier range. Since their capacitances are at least an order of magnitude larger than those of reverse-biased p-i-n diodes of comparable area, these devices must be used with low-input-impedance circuits at large bandwidths. This reduced high-frequency sensitivity is compensated for, at least in part, by the high light levels used in photovoltaic applications.

## II. SIGNAL FORMAT AND OPTICAL METHODS

The block diagram of Fig. 1 identifies major components of the demonstration signalling stations. Each station transmitted and received a complete television channel and an audio bandwidth FM channel via a single-strand fiber lightguide. The local station depended entirely on electric utility power and the remote station only partly so. If utility power failed at the remote station, bidirectional speech and sound-alert capabilities were automatically maintained by photovoltaic conversion of optical power arriving from the local station. The local-station laser was continuously operated at high enough powers to ensure these capabilities regardless of how the remote station was being powered.

The remote-station laser was a low-operating-current, GaAs, buried-stripe heterostructure (BSH), producing 50 to 100 microwatts of single-ended power at wavelength $\lambda_2 = 0.885\ \mu m$, predominately in the lowest-order spatial modes; the local-station laser was a planar stripe GaAlAs double heterostructure emitting up to 3 mW at wavelength $\lambda_1 = 0.84\ \mu m$. The FM and TV signals, produced by microphone (MIC)-modulated variable-frequency oscillators (VFOs) and video-cassette recorders (TV-3) or color-bar generators (TV-4), were superimposed on adjustable laser bias currents. The laser emissions were focussed into short fiber pigtails by high-refractive-index glass microlenses and delivered to the transmission lightguide by GRIN-lens bidirectional couplers.[4] Each coupler utilized colinear quarter-period lenses, separated by a dielectric multilayer of high reflectivity at $\lambda_1$ and high transmission at $\lambda_2$, to obtain the wavelength combinations shown by the dashed line in Fig. 1.

Light of wavelength $\lambda_1$ was directed onto a GaAs double-heterostructure photodetector in the remote station. High-frequency photocurrent was capacitor-coupled to the FM and TV receivers, while the photovoltaic dc component provided steady-state operation of the FM receiver and of a low-duty-factor, pulse-amplitude-modulation (PAM) transmitter. In the absence of electric utility power, speech transmission switched automatically to this PAM standby channel. The micro-




$V_B$ – SUPPLY VOLTAGE, ELECTRIC-UTILITY POWERED
NC – NORMALLY CLOSED SWITCH POSITION

Fig. 1—Block diagram of optics and circuits in local and remote stations.

phone and speaker were housed in a telephone handset. When the handset was on-hook, a photovoltaic-powered sound alert could be activated by a manually controlled switch in the local station. Optical signals of wavelength $\lambda_2$ arriving at the local station were directed onto

a silicon avalanche photodetector (APD) connected via an impedance-matching transistor to the TV, FM, and PAM receivers.

## III. IMPLEMENTATION

The quantum efficiencies and photovoltaic form factors measured at low frequencies for remote-station detectors were comparable with values reported[3] for similarly processed devices of the same nominal layer dopings and thicknesses. Design variations in the *p*-side contact diameter and in the diameter and depth of the proton-bombarded region produced device capacitances ranging between 30 and 1000 pF. Detectors near the lower end of this capacitance range had the typical small-signal frequency response illustrated in Fig. 2 and also exhibited short-circuit, pulsed-current decay times of 5 to 10 ns, consistent with reported[5,6] electron lifetimes. Although photovoltaic double-heterostructure diodes are not optical detectors of choice in low-light-level, wideband applications, they provided acceptable reception of TV channels 3 and 4 at prevailing light levels when connected to untuned 75-ohm loads. Dispersion was not a factor in limiting the quality of television reception for the 0.5-km to 1.5-km-length graded-index lightguides used during various phases of this work.

Frequency modulation at 10.0 MHz was chosen for the telephony channel to maintain compatibility with simultaneous television recep-

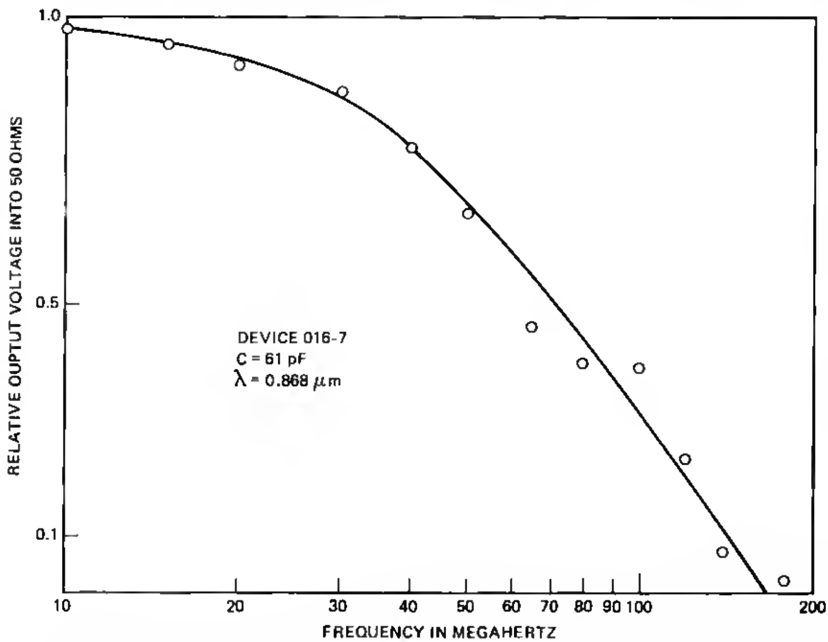



Fig. 2—Frequency response of GaAs photovoltaic detector with 50-ohm load.

tion, and particularly to avoid audio-frequency cross modulation of the TV displays. Strong FM limiting was provided at the local-station, variable-frequency oscillator in lieu of expending photovoltaic power to achieve amplitude limiting at the remote-station receiver. The receiver utilized a one-transistor FM → AM slope detector to obtain linear demodulation over a ±50 kHz range, followed by a two-transistor audio amplifier which produced comfortable sound volume (approximately 0.3 volt peak-to-peak) in a 600-ohm earphone. The receiver drew about 70 $\mu$A at 0.90 volt from the photovoltaic detector. During optically powered operation, the PAM transmitter produced 25- to 40-mA current pulses of 100-ns duration in the remote station laser at 12-kHz repetition rate.

The quarter-period graded-refractive-index (GRIN) lenses* used in the bidirectional couplers were 4.0 mm long and 1.5 mm in diameter. They were aligned along a common optical axis and cemented to a 1.1-mm-thick glass flat on which a long-wavelength-pass, sharp-transition, dielectric-multilayer filter had been deposited. (The filters were supplied by Optical Coating Laboratories, Inc.. Design procedures for this type of edge filter are summarized by H. A. MacLeod.[7]) Three 100-cm-long, connectorized, lightguide pigtails were manipulated into optimum coupling position in a sequence that allowed some compensation for previous component misalignment, and were affixed to the GRIN-lens faces with ultraviolet-curing cement. The insertion losses versus wavelength of a typical bidirectional coupler, epoxied into an aluminum housing for protection, are shown in Fig. 3; combined losses of the coupler pair used in the present work were 1.5 dB or less in either channel. Crosstalk protection was particularly important at the local station where the power at $\lambda_1$ was much larger than at $\lambda_2$. The coupler provided approximately 30 to 35 dB of cross-talk protection, and a GaAlAs band-edge filter[1] cemented to the APD added an additional 17 dB. No crosstalk effects were observed at either station.

Graded-index, cabled lightguide of 50-$\mu$m core diameter and 0.22 numerical aperture was used throughout the final assembly. At either station the laser emission injected into the lightguide link was enhanced by thermally forming[8] a glass lens on the end of an optical fiber pigtail. Substantially hemispherical, 125-$\mu$m-diameter lenses in the refractive index range 1.9 to 2.1, made from low-melting-temperature glasses of high lead-oxide content, refracted 70 per cent of the laser output-facet emission into the optical guided modes. The lensed pigtail was epoxied into position relative to the laser to deliver maximum output power.

* These lenses were of the SLW type supplied by Orient Glass, Inc.

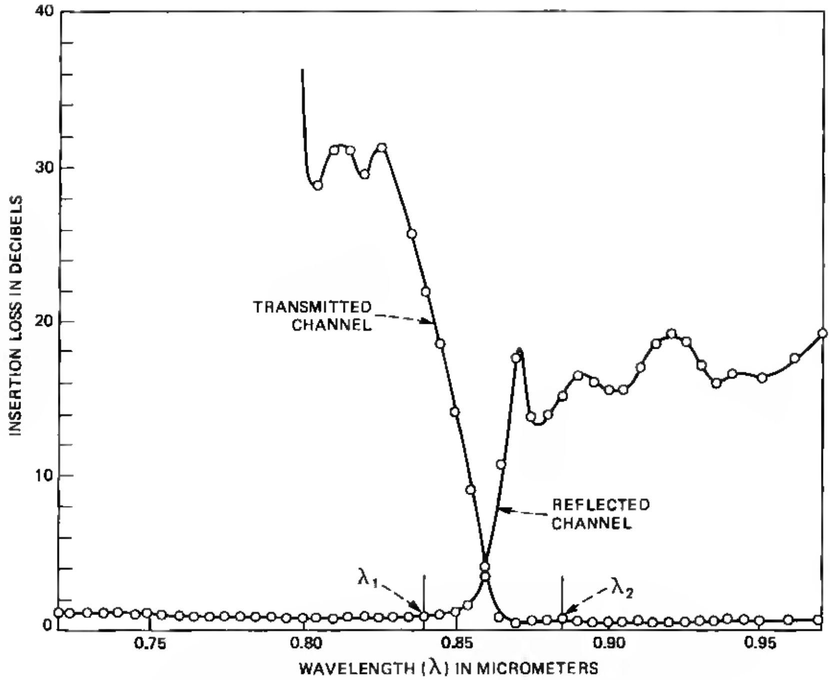



Fig. 3—Bidirectional characteristic of GRIN-lens coupler.

## IV. PERFORMANCE

The local-station laser bias current was adjusted to produce a 0.90-volt dc level at the remote station, a photovoltage at which the optically powered circuits of Fig. 1 drew currents in the range of 220 to 280 $\mu$A. The optical power incident on the photovoltaic detector at wavelength $\lambda_1 = 0.84$ $\mu$m was 0.65 mW, yielding a 1.0-volt open-circuit voltage, 330-$\mu$A short-circuit current, and a photovoltaic power conversion efficiency of 0.34 at the circuit operating point. (Substantially larger efficiencies have been reported[3] for optimum loading at higher optical powers.) The cabled lightguide link was 0.5 km long. The loss at $\lambda_1$ was 4.7 dB, comprised of 1.5-dB laser-to-lightguide coupling loss, 1.2-dB bidirectional-coupler-pair insertion loss, and 2.0-dB lightguide transmission loss. Hence 2.0 mW of local-station laser emission were needed to power the remote station optically. This power was increased to 3 mW for sound alerting. Alerting relied on charge storage during silent portions of the sound-alert format to lessen the laser power requirements compared to an earlier[2] method; acoustic power bursts of about 0.3-mW peak and 0.5-second duration were generated at 1.4 kHz, the alerter resonant frequency.

Television reception via the optical link was subjectively indistin-

guishable from that obtained by connecting the receivers via 75-ohm cable to the TV-4 color-bar generator or to the video cassette TV-3 output. Speech reception of good commercial telephone quality was observed subjectively at either station under both electrically and optically powered conditions, and the transition between electrical and optical powering of the remote station occurred without significant alteration in audio quality.

## V. CONCLUSIONS

The ability of double-heterostructure photovoltaic devices to detect high-frequency optical modulations, while providing efficient photovoltaic generation of dc power, has been established. The feasibility of bidirectional speech-television communication over a lightguide link, with speech communication capability during utility power outages at the remote station, was demonstrated.

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